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The Survival of Hatchery-Reared Salmon Fry in some Scottish Streams

By D. H. MILLS, M.Sc., Ph.D.

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The Survival of Hatchery-Reared Salmon Fry in some Scottish Streams

INTRODUCTION

In many salmon management programmes stress is frequently laid on the possibility of increasing salmon stocks either by planting salmon ova or introducing young salmon into areas that are either inaccessible to spawning adults or considered under-populated. This practice is followed in river systems affected by hydro-electric schemes where, because of low water flows due to water abstraction and diversion, ascending adult fish may have to be trapped some distance below the spawning and nursery areas and stripped of their eggs which are transferred to a hatchery. Though the young may be introduced into suitable areas either as fry, parr or smolts, most introductions are made at the unfed fry stage, that is, the immediate post-alevin stage when yolk sac absorption is almost complete. Although this practice has been carried out for a number of years, until recently no assessment had been made of the survival of the fry or the effects of introducing them at various densities. The practice of the Fishery District Boards' personnel has been to introduce the fish into streams at random and sometimes without much regard to the carrying capacity of the stream concerned.

Mills (1964, 1965) has described the survival to the smolt stage of hatchery-reared salmon fry released into the River Bran (Ross-shire) and some of its tributaries. This paper gives an account of the survival of fry during their first year of life in this river system, following stocking at various densities.

THE STREAMS STUDIED

The streams chosen for this study were Allt a' Chomair (Nat. Grid ref. NH 206602), Allt dos Mhuicarain (Nat. Grid ref. NH 210605) and Allt Coire nan Laogh (Nat. Grid ref. NH 172585). These streams flow into the upper reaches of the River Bran, between Achnasheen and Achanalt. A detailed description of this river system has been given in an earlier paper (Mills, 1964).

Allt a' Chomair is about 6160 yards (5630 m) long and has an average annual flow of 24 cusecs (0·7 m^3/sec). Allt dos Mhuicarain is about 2640 yards (2415 m) long and has an average annual flow of 7 cusecs (0·2 m^3/sec) and Allt Coire nan Laogh is about 2640 yards (2415 m) long and has an average annual flow of 9 cusecs (0·2 m^3/sec). These streams are chemically poor and base-deficient (Table 1) and flow over pelitic gneiss, siliceous and granulitic schists of the Moine series, much of which is peat and drift covered. In their upper reaches the three streams flow through areas of deer grass and heather moor, *Molinia-Myrica* swamp, *Sphagnum* bog and, lower down, through *Molinia* grassland with *Juncus effusus* along the banks.

TABLE 1

THE CHEMICAL ANALYSES OF WATER SAMPLES FROM ALLT A' CHOMAIR, ALLT DOS MHUICARAIN AND ALLT COIRE NAN LAOGH

	Conductivity (mhos/cm at 20°C)	pH	Alkalinity (p.p.m. $CaCO_3$)	Na^+ (p.p.m.)	K^+ (p.p.m.)	Ca^{++} (p.p.m.)	Mg^{++} (p.p.m.)	Cl^- (p.p.m.)	SO_4^{--} (p.p.m.)
Allt a' Chomair[1]	?	6·25	2·4	8·7	0·5	3·1	1·2	16·8	5·9
Allt dos Mhuicarain	33	5·85	0·6	4·3	0·3	1·1	0·5	7·9	2·9
Allt Coire nan Laogh	29	6·30	1·6	3·8	0·3	1·0	0·5	6·3	2·5

[1] Mean of five readings

The stream section in which fry were planted in Allt dos Mhuicarain has a substrate of flat stones with a few emergent rocks, many with permanent moss covering and, during the summer, some algae. The substrate of Allt a' Chomair and Allt Coire nan Laogh consists of coarse gravel, loose angular stones, emergent rocks and, upstream, exposed bed rock. There is no moss on the stones and only a scanty algal covering during the summer.

Details of the bottom fauna of Allt a' Chomair have been given by Mills (1964) and of Allt dos Mhuicarain by Mills (1964), Egglishaw (1964) and Egglishaw and Mackay (1967). The bottom fauna in both these streams is sparse. The bottom fauna of the third stream, Allt Coire nan Laogh, has not been studied in detail but this stream is generally similar to the other two streams.

All three streams contained brown trout and salmon parr, the latter having come from the main river where they had been planted as fry. No salmon spawn in these streams.

METHODS

Wolf-type traps in which the horizontal framework was covered with 1/10 in (2·5 mm) wire mesh were built near the mouths of Allt dos Mhuicarain and Allt a' Chomair. In general, these traps worked well and provided a satisfactory record of the downstream movement but there were times when they were out of operation for short periods due to floods. The fry were added to Allt a' Chomair over an area of 4915 square yards (4100 m^2) bounded downstream by the trap and upstream by a small fall which could be negotiated by fish after their first year. In Allt dos Mhuicarain the fry were placed in a section of 1270 square yards (1060 m^2). The area was bounded by the trap downstream and the upstream boundary consisted of falls which are impassable to ascending fish. The area available to fry in Allt Coire nan Laogh is 3630 square yards (3032 m^2), the upper limit again being a series of inaccessible falls but, as there was no trap near the mouth of this stream, fish could move freely in or out.

The time of release of the fry depended on the rate of their development in the hatchery, and was usually between the end of April and the middle of May. The fry were transported from the North of Scotland Hydro-Electric Board's hatchery at Contin by lorry in tanks supplied with air. The transport period was approximately 30 minutes.

Each autumn a census of the fish populations of the three streams was made using electric fishing apparatus which was battery-powered and produced a pulsed direct current of 500 volts. All the salmon fry, salmon parr and brown trout caught were measured and their weights estimated from known length-weight relationships.

From 1960 to 1962 all the fish caught were fin-clipped and returned to the stream. From 1963 onwards, all fish were removed from Allt a' Chomair and Allt dos Mhuicarain after the census because it was evident that the presence of older fish was affecting fry survival. This was one of the factors which caused the wide variation in the densities of older fish shown in Table 3. Even so, it was found that some parr were always present at the census in the following year and it was assumed that these were fry of the previous year which had not been caught and adjustments were made in the survival estimates accordingly. It was also found that the brown trout populations had regained their previous densities, presumably because they had moved into the areas from upstream. As Allt Coire nan Laogh had no trap at the mouth no attempt was made to remove the fish from this stream.

RESULTS

In an earlier paper (Mills, 1964) it was shown that most of the fry taken in the traps at the mouth of Allt a' Chomair and Allt dos Mhuicarain were caught within the first five weeks after planting. This may have been due to dispersal or emigration because of high population density (Kalleberg, 1958) or food shortage (Wynne-Edwards, 1962, p. 139). Over the period in which the majority of the fry passed downstream daily numbers entering the traps were compared with the rainfall figures for the previous 24 hours. The results showed that the numbers of fry entering the traps increased with a rise in water

level and a consequent increase in flow. It was also noted that the majority of the fry entered the traps during the hours of darkness.

As is shown in Table 2, some of the fry moved out of the streams in which they were stocked during the period following stocking. One factor affecting this movement is clearly stocking density as high proportions of migrants are associated, for both streams, with high stocking densities. Stocking density is, however, not the only factor involved because in some instances, notably in Allt a' Chomair in 1963, a high stocking density produced only a modest downstream movement and something similar happened, in the same year, in Allt dos Mhuicarain. In both these cases, however, the densities of the salmon parr and trout populations were low when the census was made in the late summer and presumably were in a similar state when the salmon fry were added in the spring. The numbers of other fish present is therefore another factor affecting movements after stocking.

TABLE 2

TRAP CATCHES OF FRY IN ALLT A' CHOMAIR AND ALLT DOS MHUICARAIN, IN RELATION TO STOCKING DENSITY AND POPULATION DENSITY OF OLDER FISH IN THE STREAMS

Year	Stocking density (no./m²)	Density of salmon parr and trout at census (no./m²)	Percentage of fry planted entering traps
ALLT A' CHOMAIR			
1960	12·73	0·07	24·6
1961	12·42	0·08	15·5
1963	13·23	0·03	5·9
1964	3·09	0·15	3·3
1965	3·00	0·10	1·4
ALLT DOS MHUICARAIN			
1960	15·24	0·28	18·0
1963	15·52	0·07	9·0
1964	3·43	0·18	2·5
1965	3·53	0·15	3·1

The results set out in Table 3 indicate that there does not seem to be a clear relationship between stocking density and the population density of the fry present at the end of the summer, but that the latter is affected by the number of older fish (salmon parr and trout) which are present. At least for Allt dos Mhuicarain and Allt a' Chomair, if more salmon parr and trout are present, the population density of the fry surviving is lower, but this relationship does not seem to apply to Allt Coire nan Laogh in 1963 and 1964. The reasons for this are not clear.

The population densities of fish in Allt a' Chomair and Allt Coire nan Laogh are of similar order, while the population density of fish in Allt dos Mhuicarain is much higher and this is probably due to the substrate. Both Allt a' Chomair and Allt Coire nan Laogh have substrates of coarse gravel, loose angular stones and emergent rocks while in Allt dos Mhuicarain the substrate consists of larger flat stones, laying on coarse gravel, with a covering of water moss (*Fontinalis* spp.) and algae.

In Allt a' Chomair and Allt Coire nan Laogh the total weight (g./m²) or standing crop of fish was very similar each year, but in Allt dos Mhuicarain there was a substantial increase in 1964 when the standing crop was 4·25 g./m². The main reason for this increase seems likely to be an increase in the nutrients available produced by (a) the addition, in 1963 and 1964, of mineral fertilizers to the loch at the head of this stream by the owner and, (b) the increased discharge from a septic tank which flows into the stream. In the year following this increase the total weight of fish had returned to the values occurring before fertilization, suggesting that the effects of fertilization had been short-lived.

The standing crop of fry in the three streams varied from year to year (Table 4) depending on their survival. The growth rate of the fry also varied from year to year. This was not related to population density, as in brown trout fry (Le Cren, 1962, 1965), but more probably to food availability and climatic

TABLE 3

DISPOSITION OF SALMON FRY AFTER PLANTING

	1960	1961	1962[b]	1963	1964	1965	1966
ALLT DOS MHUICARAIN							
Stocking density (unfed fry/m²)	15·24	—[a]	—[b]	15·52	3·43	3·53	3·65
Density at census (fry/m²)	0·20	—[a]	—[b]	0·93	0·80	0·36	0·39
Percentage surviving in stream at census	1·3	—[a]	—[b]	6·0	23·3	10·2	10·6
Density of salmon parr and trout at census (no./m²)	0·28	—[a]	—[b]	0·07	0·18	0·15	0·11
Standing crop of fish (g./m²)	2·70	—[a]	—[b]	2·94	4·25	2·81	2·83
ALLT A' CHOMAIR							
Stocking density (unfed fry/m²)	12·73	12·42	—[b]	13·23	3·09	3·00	3·02
Density at census (fry/m²)	0·18	0·11	—[b]	0·61	0·15	0·22	0·39
Percentage surviving in stream at census	1·4	0·8	—[b]	4·6	4·9	7·3	12·9
Density of salmon parr and trout at census (no./m²)	0·07	0·08	—[b]	0·03	0·15	0·10	0·07
Standing crop of fish (g./m²)	1·17	0·96	—[b]	1·04	1·18	1·34	1·66
ALLT COIRE NAN LAOGH							
Stocking density (unfed fry/m²)		5·5	5·5	1·7	1·7		
Density at census (fry/m²)	No	0·07	0·16	0·54	0·15	No	
Percentage surviving in stream at census		1·3	2·9	30·3	8·5		
Density of salmon parr and trout at census (no./m²)	Stocking	0·20	0·12	0·19	0·23	Stocking	
Standing crop of fish (g./m²)		1·27	1·09	1·95	1·93		

—[a] Samples of fry collected at weekly intervals for feeding studies (see Egglishaw, 1967)

—[b] Severe flooding occurred at time of release of fry

TABLE 4

MEAN LENGTH AND WEIGHT OF SALMON FRY AT END OF FIRST SEASON

Year	No. of fish	Mean length (cm.)	S.E.	Weight (g./m²)
ALLT A' CHOMAIR				
1960	767	4·81	±0·019	0·24
1961	462	4·32	±0·023	0·10
1963	2133	4·06	±0·011	0·48
1964	650	4·05	±0·014	0·12
1965	899	4·90	±0·014	0·29
1966	1595	4·93	±0·011	0·50
ALLT DOS MHUICARAIN				
1960	206	4·83	±0·026	0·29
1963	991	5·37	±0·019	1·80
1964	853	5·75	±0·018	1·71
1965	389	6·07	±0·023	1·00
1966	413	5·75	±0·025	0·83
ALLT COIRE NAN LAOGH				
1961	224	3·97	±0·028	0·05
1962	486	4·42	±0·019	0·15
1963	1630	4·86	±0·010	0·67
1964	466	4·21	±0·019	0·11

conditions. In years when floods are frequent the bottom fauna is more likely to be sparse due to the scouring action of the unstable beds of these streams, particularly those of Allt a' Chomair and Allt Coire nan Laogh.

DISCUSSION

Some of the reasons for the downstream movement of salmon fry are suggested by the observations made by Kalleberg (1958) in a stream tank. He found that salmon fry tended to disperse when they began to feed, that feeding was common among the fry three to four days after emergence from the gravel and that during the first two weeks the feeding behaviour exhibited an increasing specialization by being directed towards open water. Le Cren (1961) found that experimental populations of brown trout fry also tended to disperse in the limited area available to them and considered that dispersal was probably more important under completely natural conditions.

Kalleberg (1958) also found that, at moderate population density and normal current velocity, all juvenile salmon in an aquarium occupied territories and suggested that the reason why territories were finally abandoned might be increasing competition within the population because the individual had outgrown its environment, or changes of water current. He suggested that the velocity of current influences young salmon by (a) forcing the fish to leave exposed stations, and so acting directly on territoriality and, (b) by affecting the special adjustment of juvenile salmon and trout to drifting prey. Following the definition of Noble (1939) the word territory is used to describe 'any defended area'. A 'station' is the restricted area within a 'territory' where the resident animal spends most of its time. Some evidence indicates that at night young salmon do not defend territories but settle down between stones on the stream bottom to rise again and occupy their territories in the morning (Kalleberg, 1958). Kalleberg also found that, in an aquarium, if the fry density exceeds a critical limit the population splits into two fractions, one occupying territories and the other, with no territories, being markedly unstable. Presumably it is the unstable fraction of the population which disperses initially and, in the case of Allt a' Chomair and Allt dos Mhuicarain, was recorded at the traps. This therefore suggests there is a critical density for stocking fry, which is supported both by Le Cren's findings and the present results.

The fry mortality at certain stocking densities was found to be extremely high and Marr (personal communication) has suggested that the stage at which unfed fry are introduced into streams is important and that if the nutrients in the yolk sac have been completely used up some days before the fry are liberated, mortality could well be high. In the present investigations care was taken to ensure that fry were released while the yolk sac was still visible. Miller (1954) found that hatchery-reared cutthroat trout (*Salmo clarkii*) do not compete successfully for food or territories with mature resident trout in the area of planting. Even other wild trout taken from a stream that contains mature fish are slow to secure adequate living space. Apparently the resident fish has an advantage over newcomers, whether hatchery-reared or wild. Planted fish must compete with these residents for space and for food. During this competition they must constantly cope with stream flow and some may become exhausted and die while others disperse downstream. Barrow (1955) has suggested that territorial behaviour may also be important for other aspects of the freshwater life of young salmon. If food acquisition is the primary function of these territories, fish which are able to maintain territories most successfully will have access to the best food supply and should grow fastest. Those which are less successful will live in areas where food is scarcer. These fish may be in sub-optimal physical condition, and will then be more susceptible to predation and even to parasites. However, Le Cren (1961) also found that mortality in his brown trout populations could be as high as 97% if the stocking rate was very high and Horton (1961) found a mortality of between 92% and 96% between alevin and yearling stages of brown trout under natural conditions. Le Cren also found that deaths probably occurred between 20 and 40 days after the fish began to feed.

Egglishaw (1967) in referring to the findings of Mills (1964) inferred that it was not simply a high stocking density which was responsible for the heavy fry mortality in Allt dos Mhuicarain as higher densities of salmon fry occur in the Shelligan Burn which he studied, and in artificial rearing conditions. He went on to say that 'rather it is a lack of correspondence between the stocking density and the stream's

capacity to provide the necessary requirements of territory, feeding stations, shelter and food for the normal life of the fry that leads to the high mortality'. These are, in fact, the factors Mills (1964) noted in discussing the heavy fry mortality at high stocking densities. It is common knowledge that some waters have a higher carrying capacity than others, and a comparison with artificial rearing conditions is irrelevant.

In the present investigation, it is not known how much of the predation on the salmon fry is attributable to trout and how much to salmon parr. However, Backiel and Le Cren (1967) showed that the mortality coefficient of salmon appeared to be proportional to the total population density of salmon plus trout, whereas the mortaility coefficient for the trout was not influenced by the numbers of salmon present.

Further, in all salmon hatcheries the fish are crowded together much more closely than in nature. Under such conditions Keenleyside and Yamamoto (1962) showed that territorial behaviour is suppressed. Little is known about the effect this suppression may have on the ability of hatchery fish to survive when released in rivers.

Differences in the densities of fish in Allt dos Mhuicarain, Allt a' Chomair and Allt Coire nan Laogh can be explained on the basis of the findings of Kalleberg (1958) who showed that in streams with large stones (e.g., Allt dos Mhuicarain) there are more but smaller territories available for fish owing to fish being out of sight of each other, while in streams with only a few stones on a substratum of gravel (e.g., Allt a' Chomair and Allt Coire nan Laogh), territories were necessarily large due to the antagonistic behaviour of neighbouring fish. This finding is corroborated by Saunders and Smith (1962) who have shown that the population of brook trout (*Salvelinus fontinalis*) over one year old in a small stream depends upon the hiding places available. After they increased the number of hiding places the population almost doubled. It is also significant that there was no change in the growth rate so the population and production had been limited not by the food supply in this case but by the physical configuration of the stream.

Because an increased weight of fish in Allt dos Mhuicarain in 1964 might have been due to the addition of mineral fertilizers to the loch at the head of this stream in 1963 and 1964 it was decided to add fertilizer to Allt a' Chomair in 1966 to see what effects the direct addition of fertilizer to the stream had on fish production. Calcium superphosphate was added in April and June at a concentration of 2·5 cwt/acre. The fertilizer was mixed with sand and placed in hessian bags sited in the quieter reaches of the stream to prevent immediate washout. At the population census in September the standing crop of fish was found to be 10 per cent higher than in 1965 and 19 per cent higher than in 1964. However, because in 1965, when there was no fertilization, the standing crop value was 11 per cent higher than in 1964, the increase in 1966 may not necessarily be attributable to the addition of fertilizer. Due to severe flood conditions at the time of fry release in 1967 complete figures, which might have indicated an improved production, were not available.

APPLICATIONS

In this particular study the results indicate that high stocking rates in streams of this character (12·0 to 15·0 fry/m^2) are wasteful of fry and that a similar production of young fish can be achieved by introducing small numbers (2·0 to 5·0 fry/m^2), thus allowing the hatchery production to be used to better advantage. However, the rate of stocking should not be so low as not to provide reasonable insurance against natural incidents. Owing to the variation in survival due to the population density of older fish it is less easy to provide a reliable guide to the numbers of fry to be released in an area to give a certain survival. Obviously where no other fish are present hatchery planting in the first year will be uncomplicated, where the only species are salmon and trout it may be decided to remove the trout before fry planting to reduce predation, although salmon parr are also predators. However, a reduction in the trout population may only be temporary and, as has been shown in this paper and by Mills (in the press) recolonization can take place quite quickly, so while trout reduction may be worthwhile in limited areas, to attempt a large scale reduction in a river system would probably be less successful. In situations where it is known that older fish are present it would be more useful to reduce stocking rates in alternate years. Where several fish species are present the inter-relationships may be so complex that no hard and fast rule can apply.

In none of the streams studied was the density of the fry population in the autumn more than 1·0/m², though values approaching this level occurred in Allt dos Mhuicarain in 1963 and 1964, when the loch at the head of the stream was fertilized. Excluding the values for this stream in these two years, the average density of fry present in the autumn in Allt dos Mhuicarain, Allt a' Chomair and Allt Coire nan Laogh was 0·31, 0·27 and 0·26/m² respectively. A population density of this order is, however, probably unusually low. Le Cren (1961) found populations of 7 brown trout fry/sq. yd. (8·3/m²) in small streams in the Lake District and Egglishaw (1967) found the salmon fry population density to be 10/m² in the Shelligan Burn, a stream running through agricultural land and cattle pasture in Perthshire.

There is evidence that, under certain conditions, fertilization of a stream may produce beneficial results. From the results described in this paper it would appear that a fertilized loch at the head of a stream produces better results than the addition of fertilizer to the stream itself. However, Huntsman (1948) placed bags of fertilizer on the shores of a barren stream in Nova Scotia and found that the effects were beneficial with a resulting growth of algae, rooted plants in the mud and an increased survival of planted salmon fry when previously few had survived. Jones (1957) points out that before this experiment the stream, which was shallow, was not overcrowded with fish, and it carried very little fauna and flora. Whether the effects of such fertilization would be apparent on fertilizing a normal or overcrowded stream is very doubtful.

Finally it should be emphasized that where natural spawning occurs there is little advantage gained by introducing hatchery-reared fry. Unless the number of spawners is obviously too low for the area to be adequately occupied by their progeny, the number of individual fry and parr resulting from natural spawning will in most cases very soon adjust itself to a level corresponding to the amount of space and food available. If more fry are added the competition is increased and many of either the introduced fry or those already present will die, the equilibrium will be restored and little or nothing will be gained.

ACKNOWLEDGEMENTS

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SUMMARY

1. Three moorland streams were stocked with unfed salmon fry at various densities.

2. Records from traps set up at the mouths of two of the streams revealed a high proportion of fry moving out of the stream, within the first few weeks after release, if stocking density was high.

3. The numbers of older fish present in the stream affect the movements and survival of fry.

4. In two of the streams the standing crop of fish was very similar each year (1·0 to 2·0 g./m²) ; but in the third stream there was a substantial increase in one year when the standing crop rose from an average of 2·8 g./m² to 4·2 g./m². The main reason for this increase seems likely to be an increase in the nutrients available produced by (a) the addition of mineral fertilizer to the loch at the head of this stream and, (b) the increased discharge from a faulty septic tank.

5. The standing crop of fry in the three streams varied from year to year. The growth rate of the fry also varied from year to year, but this was not evidently related to population density. It may have been affected by the availability of food and by climatic conditions.

6. The study indicates that high stocking rates (12·0 to 15·0 fry/m²) in moorland streams of the type studied are wasteful of fry and that a similar production of young fish can be achieved by introducing small numbers (2·0 to 5·0 fry/m²).

REFERENCES

BACKIEL, T. and LE CREN, D. D. 1967. 'Some density relationships for fish population parameters.' In Gerking, S. D. (Ed.). *The Biological Basis of Freshwater Fish Production*, Oxford: Blackwell.

EGGLISHAW, H. J. 1964. 'The distributional relationship between the bottom fauna and plant detritus in streams.' *J. Anim. Ecol.*, **33**, 463–76.

EGGLISHAW, H. J. 1967. 'The food, growth and population structure of salmon and trout in two streams in the Scottish highlands.' *Freshwat. Salm. Fish. Res.*, 38, 32 pp.

EGGLISHAW, H. J. and MACKAY, D. W. 1967. 'A survey of the bottom fauna of streams in the Scottish Highlands. Part III. Seasonal changes in the fauna of three streams.' *Hydrobiologia*, **30**, 305–34.

HORTON, P. A. 1961. 'The bionomics of brown trout in a Dartmoor stream.' *J. Anim. Ecol.*, **30**, 311–38.

HUNTSMAN, A. G. 1948. 'Fertility and fertilisation of streams.' *J. Fish Res. Bd Can.*, **7**, 248–53.

JONES, J. W. 1957. 'Fertilisation of waters.' *Trout and Salmon*, **2**(8), 11–12.

KALLEBERG, H. 1958. 'Observations in a stream tank of territorality and competition in juvenile salmon and trout (*Salmo salar* L. and *S. trutta* L.).' *Rep. Inst. Freshwat. Res. Drottningholm*, 39, 55–98.

KEENLEYSIDE, M. H. A. and YAMAMOTO, F. T. 1962. 'Territorial behaviour of juvenile Atlantic salmon (*Salmo salar* L.).' *Behaviour*, **19**, 139–69.

LE CREN, E. D. 1961. 'How many fish survive?' *River Boards Association Year Book*, No. 9, 57–64.

LE CREN, E. D. 1962. 'The efficiency of reproduction and recruitment in freshwater fish.' In Le Cren, E. D. and Holdgate, M. W. (Eds.). *The Exploitation of Natural Animal Populations*, Oxford: Blackwell (pp. 283–96).

LE CREN, E. D. 1965. 'Some factors regulating the size of populations of freshwater fish.' *Mitt. inst. Verein. theor. angew. Limnol.*, **13**, 88–105.

MILLS, D. H. 1964. 'The ecology of the young stages of the Atlantic salmon in the River Bran, Ross-shire.' *Freshwat. Salm. Fish. Res.*, 32, 58 pp.

MILLS, D. H. 1965. 'Studies of the survival of salmon fry and their application.' (Abstract.) *Rep. Challenger Soc.*, **3**, XVII, 33–34.

MILLS, D. H. 1969. 'The survival of juvenile Atlantic salmon and brown trout in some Scottish streams.' *Symposium on Salmon and Trout in Streams, H. R. MacMillan Lectures in Fisheries, 1968.* University of British Columbia, Vancouver, Canada.

NOBLE, G. K. 1939. 'The role of dominance in the social life of birds.' *Auk*, **56**, 263–73.

SAUNDERS, J. W. and SMITH, M. W. 1962. 'Physical alteration of stream habitat to improve trout production.' *Trans. Am. Fish. Soc.*, **91**, 185–88.

WYNNE-EDWARDS, V. C. 1962. *Animal dispersion in relation to Social Behaviour*, pp. xi+653, Edinburgh: Oliver and Boyd.

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